ODD Protocol

1. Overview

1.1 Purpose

The purpose of the model is to simulate the behaviour of households within a village and observe the emerging properties of the system in terms of food security. The model draws upon the Sustainable Livelihoods Framework (Chambers & Conway 1991; Scoones 1998) to consider food security outcomes of different livelihood strategies. A key aim of the model is to quantify food availability, access, utilisation and stability at both the household and village level, thereby taking into account the multidimensional nature of food security.

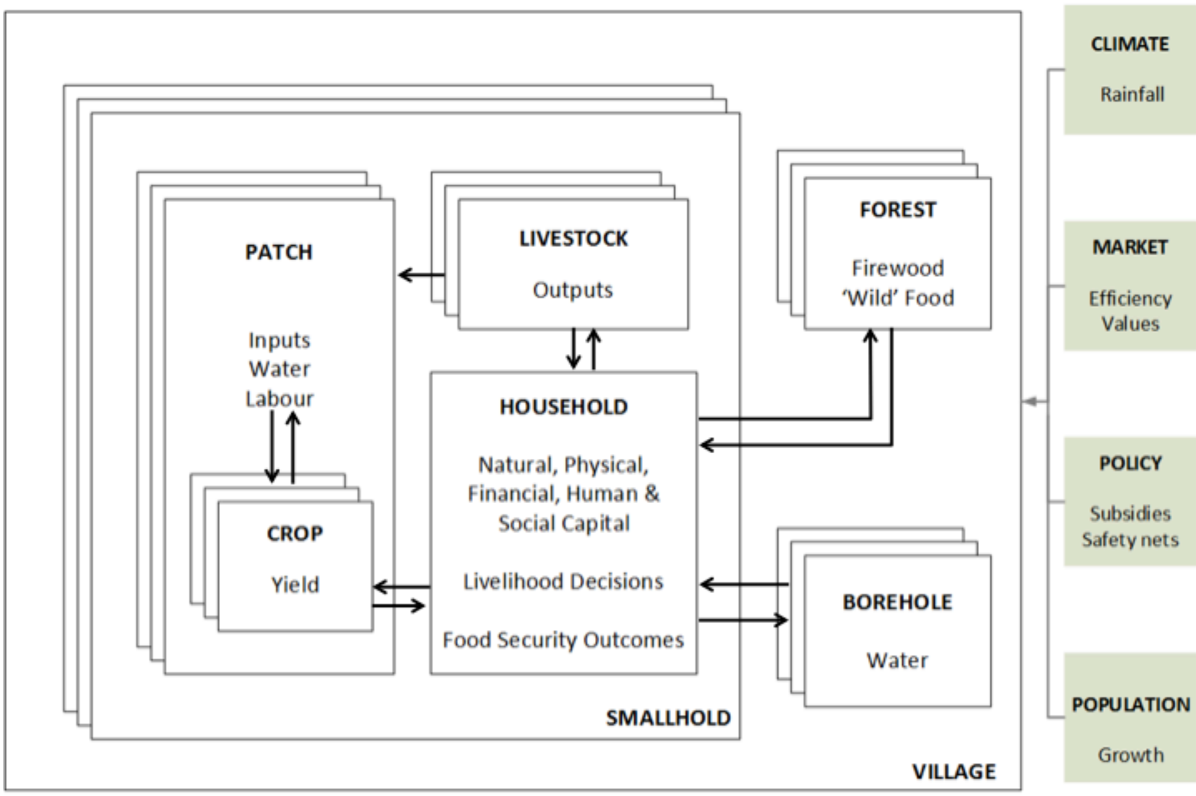


Figure 1. Schematic of key model entities and the relationships between them.

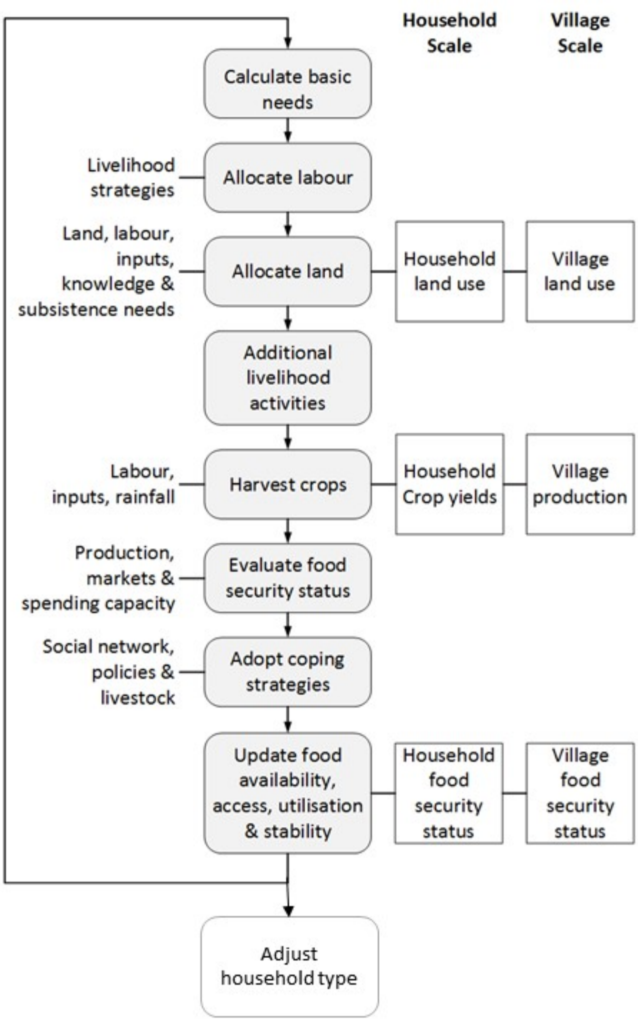
1.2 Entities, State Variables and Scales

Households are the main entity and are distinguished into three types i) farmers, ii) agricultural labourers and iii) non-agricultural workers. The household types are defined based upon a cluster analysis of household survey data described by Dobbie *et al*. (under review). The main attributes of households include human, physical, natural and financial capital. These are initialised using empirical data from the third household survey (IHS3) for Malawi (NSO 2012) and as a result are highly heterogeneous. Households interact through a social network, which is modelled as a small world with characteristically short average path lengths and high clustering (Watts & Strogatz 1998). Individuals belong to households and are defined by their gender, education, and age and are initialised using data from the IHS3 (NSO 2012).

The current environment represents a hypothetical village within Southern Malawi. The village encompasses approximately 199 hectares made up of farmland, dimba[1], forest and water. The environment is represented as a stylised 2D grid of patches with each patch corresponding to an area of land of variable size. Key attributes of the different patches include: area, fertility and ownership. These are initialised using plot level data from the IHS3 (NSO 2012). Households can own both dimba and farm plots, whilst forests and water remain communal. The model runs on a monthly time-step and is a-spatial. It is assumed that households are able to traverse the entire village boundary within a single time-step (or month). Other entities are captured in Figure 1.

1.3 Process Overview and Scheduling

During each monthly time step households go through a sequence of processes from resource allocation to harvesting and adopting coping strategies which combine to give village-level outcomes in relation to land use, food production and food security status (Fig. 2). During simulations described here, the model loops through 480 months, representing 40 years from 2010 to 2050.



[1] Farm plots typically found in areas bordering streams and rivers. Residual moisture means they can be cultivated during the dry season from April to October.

Figure 2. The sequence of processes conducted by each household during a monthly time-step. Inputs are listed on the left-hand side and outcomes on the right. Outcome variables at the household level can be aggregated to give indicators of land use, productivity and food security at the village level.

Each time-step begins by defining the month of the year and the corresponding agricultural season. Basic needs in the form of food, water and fuel are then calculated for each of the households. Household labour is allocated between productive activities, including firewood collection, water collection, on-farm agricultural activities, off-farm agricultural activities and off-farm non-agricultural work.

At the beginning of the agricultural season, households decide how to allocate their farm plots with different crops. Eleven different combinations of basic grains, annual roots, permanent roots, nuts & pulses, fruit trees, vegetables and cash crops are possible. Decisions are constrained by land, labour, subsistence, input and knowledge requirements. In the months that follow, households are able to adjust land allocation decisions based upon labour availability. In addition to farming, households may also tend to livestock, forage for wild and indigenous foods and carry out off-farm agricultural activities such as casual farm labour (ganyu) and non-agricultural employment.

Towards the end of the time-step the four dimensions of food security, namely: availability, access, utilisation and stability are quantified for each household. Food availability is determined based upon the amount of calories available from self-production and the market. The total number of calories from crops, livestock products and forage is first summed. Surplus calories are then calculated as the difference between food-needs and calories from food availability and spending capacity (the difference between household income and non-food expenses). If surplus is greater than zero it is divided into a calorie-pool that can be donated to members of a household's social network. If surplus is less than zero it is converted into a calorie deficit.

Food access on the other hand, is defined by the amount of calories accessible from food production, market purchases and coping strategies. It is calculated as a sum of equivalent calories from food production, spending capacity, payment for work programs, borrowing food from the social network and sale of livestock. The ability of a household to process this food dictates food utilisation. Potential calories are determined by food access. Actual calories can then be calculated by multiplying potential calories by the process-ability value. This is a percentage value that takes into account the proportion of water and fuel needs the household has met, as well as household health. Whether food needs of the household have been met or not is then determined and stocks of water and fuel are updated.

Food stability is a function of market stability, political stability and production stability. Market stability is defined as the coefficient of variation (CV) in annual maize price. Political stability is made up of the CV of the proportion of households with access to inputs and the CV of households with access to payment for work schemes. Production stability is calculated as the CV of maize output for the given month. Finally food security is determined based upon food availability, access, utilisation and stability. Using techniques from fuzzy logic (Zadeh 1996; Bosma et al. 2012), each household returns a value between 0 and 100 with 0 being the lowest and 100, the highest.

In addition to this value, the village food security status can be derived from indicators, summarized for each household type, including: proportion of food deficient households, mean daily food energy consumption per capita, average proportion of food energy from staples, diet diversity and access to food at the market. These indicators can also be associated with one of the four dimensions of food security (Table 1).

Table 1. Village-level indicators of food security.

Indicator [unit]	Dimension
Average availability of calories from production and the market [calories]	Availability
Average amount of accessible calories [calories]	Access
Average daily food energy consumption per capita [calories]	Access
Prop. Of food energy deficient households [%]	Access
Average diet diversity [0-8]	Utilisation
Average percentage of food energy from staples [%]	Utilisation
Average process-ability [%]	Utilisation
Coefficient of Variance of crop production [no unit]	Stability

A total of 12 time-steps constitute an agricultural season, running from June to May the following year. The livelihood strategy, or 'type' of a household may be adjusted at the end of an agricultural season. This is based upon the proportion of time allocated to farming, agricultural labour and non-agricultural work. In line with Dorward (2009), households persevering with the same livelihood strategy, or type are considered to be 'hanging in', those households who move to a type of higher yields and / or income are classified as 'stepping up' and households shifting into new, more productive activities are termed 'stepping-out'. Households following a trajectory of declining yields and income are regarded to be 'falling down' (Fig. 3).

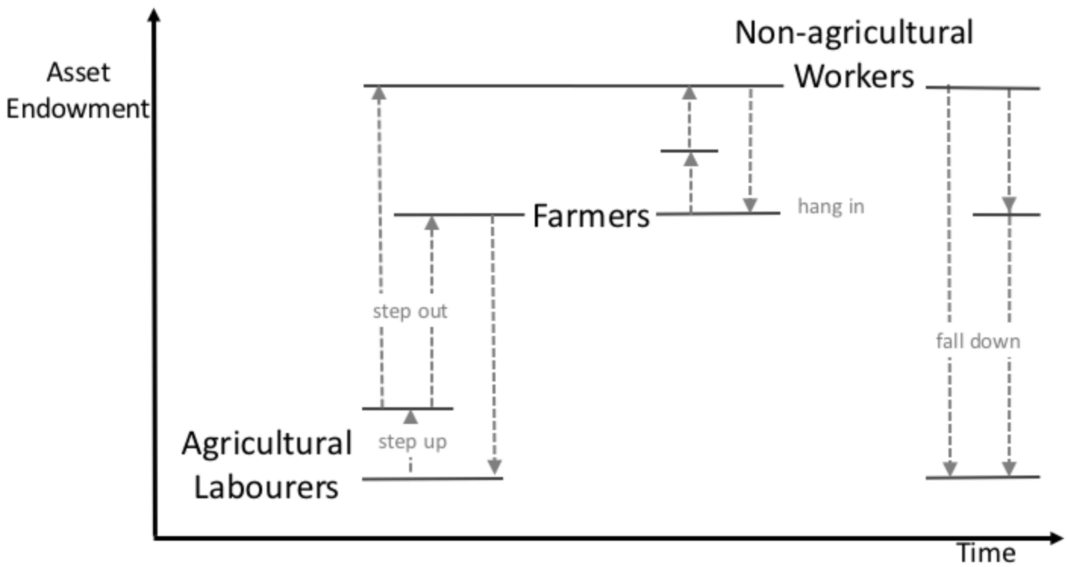


Figure 3. Conceptual diagram of household trajectories. Over time households may hang in, step up, step out or fall down.

1.4 Software Environment

The model is implemented within Netlogo 5.3 (Wilensky 1990). A total of three model extensions have been used: array, network (Wilensky 1990) and NLfuzzy (Machálek et al. 2013).

2 Model Design Concepts

2.1 Emergence

Several village-level features emerge from interactions between households and the environment. These include i) land use patterns ii) crop productivity and iii) food security status.

2.2 Adaptation

At each time-step households may employ adaptation mechanisms. These include reducing or increasing the area of land cultivated based upon available labour, as well as adopting coping strategies if the supply of calories is too low. At the end of an agricultural season, the livelihood strategy, or 'type' of a household may be adjusted to reflect changes in the proportion of time spent upon farming, agricultural labour and non-agricultural work.

2.3 Objectives

Households are driven by their need to achieve food security in terms of calories. Livelihood choices and strategies are dictated by household type, i.e. farmer, agricultural labourer or non-agricultural worker.

2.4 Learning

No learning is included in the version of the model described here.

2.5 Prediction

Households do not make predictions instead they react to information as it becomes available. The cultivation of land for example, is adjusted based upon frequent assessments of present labour availability rather than expectations regarding future labour endowments.

2.6 Sensing

Households are aware of their own variables, including subsistence needs and labour availability. These variables are important when making land allocation decisions. In addition, households are aware of their access to calories. In times of calorie deficits they may opt to carry out coping strategies. In some contexts, households may also be able to sense variables associated with other households within their social network, as well as other entities such as institutions. When considering how much firewood to extract from the forest for instance, households take into account both the past extraction habits of others, as well as the sustainable extraction levels suggested by institutions.

2.7 Interaction

The majority of model procedures describe interactions between households and the environment. These include those associated with land use and resource extraction. Households may also interact with each other through a social network to exchange land, labour, and/ or calories.

2.8 Stochasticity

Stochasticity is present within multiple model procedures. During initialisation the majority of model parameters are assigned empirically by reading in survey data. However, in a handful of cases where data was found to be insufficient, random number distributions were used to assign variables. Once the model starts iterating, a stochastic mechanism is used to determine how households allocate land to different crop types. For a few activity-based procedures such as foraging for wild food, the output for each unit of labour is drawn from a distribution consistent with survey data. The order in which households approach other households within their social network is also stochastic.

2.9 Collectives

There are three main collectives in this version of the model: i) households are aggregates of individuals, ii) social networks emerge from linked households and iii) farms consist of patches of farmland and dimba owned by a single household.

2.10 Observation

Following each monthly time step, a number of low-level and aggregated variables are collected and written to output files. Attention is given to the food security outcomes of the three different livelihood strategies: farmers, agricultural labourers and non-agricultural workers. Village-level indicators for food availability, access, utilisation and stability are described in Table 1.

3 Model Details

This section discusses the main sub-models in greater detail.

3.1 Main sub-models

3.1.1 Calculate basic needs

This sub-model calculates the food, water and fuel needs of a household. In order to calculate household calorie requirements, daily recommended calorie intake for each individual must first be evaluated, taking into account age and gender. Values are based upon those published in Smith & Subandoro (2007) for light activity. The daily calorie requirements of individuals are then summed for each household and multiplied by 30 days to yield monthly calorie requirements. In order to quantify water needs in litres, household size is multiplied by 1080, based upon GoM (2009) recommendations of 36 litres per capita per day (multiplied by 30 days). Finally fuel requirements in cubic meters of firewood are calculated using a simple subsistence equation described by Agrawal *et al*. (2013):

$$s = (hs \cdot w)/(e \cdot d) \qquad (1)$$

where *hs* is the size of household, *w* is the per capita energy requirement for cooking per month, *e* is the energy content of the wood and *d* is the average density of miombo tree species.

3.1.2 Update labour allocation

A sub-model to distribute labour between productive activities, including: firewood collection, water collection, on-farm agricultural activities, off-farm agricultural work and off-farm non-agricultural work. Total labour availability (in hours per month) is first calculated for the household. This is based upon the household type (farmer, agricultural labourer or non-agricultural worker), number of working adults, gender and health. The proportion of time spent by the household on different productive activities is then determined. Proportions are set according to household type using averages calculated from IHS3 data.

3.1.3 Update land allocation

At the start of the agricultural season, households set long-term land allocation decisions. Using simple decision trees calibrated for each household type, for each patch of land owned, households choose between 11 combinations of 6 different crop types. Decisions are constrained by land, labour, subsistence, input and knowledge requirements for each of the different crops. If the requirements are met, the household goes on to allocate land accordingly. If labour requirements aren't met, households can attempt to seek labour from their social network, otherwise the land is left to fallow.

Long-term land allocation decisions are adjusted each month based upon agricultural labour availability. The monthly labour requirements are first calculated. The area allocated to a given crop is multiplied by its corresponding labour requirements per hectare. This is then summed. If labour availability for farming meets the requirements, households distribute labour according to crop priority. Should there be any surplus labour households can allocate crops to fallow patches. If households have no fallow patches they can consider clearing forest patches instead. If labour availability for farming doesn't meet the requirements, households can attempt to seek labour from their social network.

3.1.4 Conduct livelihood activities

Households conduct a number of activities in addition to farming. These include: collecting firewood and water, tending to livestock and carrying out casual agricultural labour (ganyu). In addition, households may forage for 'wild' foods and carry out non-agricultural work. Decisions surrounding the extraction of firewood and water are simulated using a modified version of a common pool resources model described by Agrawal *et al*. (2013). Time spent upon both casual labour (ganyu) and non-agricultural work is multiplied by an hourly wage estimated from household survey data. Output in calories for time spent foraging for 'wild' foods on the other hand, is drawn from a distribution consistent with survey data. Time spent tending to livestock is also multiplied by an expected hourly output. A further procedure for livestock then determines the proportions of outputs that are eaten, sold, or lost. It is assumed that all stored outputs are eaten within the monthly time step. Proportions are based upon household type with data taken from the IHS3.

3.1.5 Harvest crops

Each month a procedure checks the crop types that are due to be harvested. Expected yield is then calculated using crop specific regression equations taking into account labour, inputs and rainfall that have accumulated during past time steps. In line with livestock activities described above, a further harvest procedure determines the proportions of crop outputs that are eaten, sold, or lost. It is assumed that all stored outputs are eaten within a monthly time-step. Again, proportions are based upon household type with data taken from the IHS3.

3.1.6 Evaluate food security status

A procedure first calculates potential food-availability from self-production and the market. The total number of calories from crops, livestock products and forage is first calculated. A sub-procedure then calculates the actual amount of calories that a households can access from self-production and the market. This takes into account crop losses and inefficient market conditions. Surplus calories are then calculated as the difference between food needs of the household and the total amount of accessible calories. If the surplus variable is greater than zero it is diverted into a calorie-pool that can be donated to members of the households' social network. If surplus is less than zero it is converted into a calorie deficit.

3.1.7 Adopt coping strategies

Households with calorie deficits may adopt coping strategies including: participation in government led food for work programs, sale of livestock and borrowing food from the social network. A procedure first determines the amount of calories from government cash-for-work and food-for-work schemes. Participation is calculated based on household type and labour availability. The value of work is drawn from distribution consistent with survey data. Income is then converted into maize calories using a conversion factor. If households still have a calorie deficit, a further procedure determines the amount of food a household can borrow from their social network. Based upon the theory of generalized reciprocal exchange (Kranton 1996), households select a neighbour from their social network at random. Calories are taken from the neighbours' calorie-pool and the households' calorie deficit is updated. If the deficit is still greater than zero, the household can select a limited number of additional neighbours (dictated by the variable *n-f-interact*). If a household still has a calorie deficit, they may consider selling livestock in order to purchase calories. The number of livestock remaining is updated accordingly.

3.1.8 Update food availability, access, utilisation and stability

Food access is adjusted to include calories available from coping strategies. A procedure then evaluates the ability of households to process calories. Techniques from fuzzy logic (Zadeh 1965; Zadeh 1996) are employed to determine overall 'process-ability' using a simple fuzzy inference system. Water, fuel and health are set to 'good', 'moderate' and 'poor' on the basis of meeting basic needs or not. Simple rules are then used to label process-ability, 'good', 'moderate' or 'poor' before being de-fuzzified to give a value between 0 and 100. Food utilisation can then be calculated by multiplying potential calories by the process-ability value. Whether food needs have been met is then determined and stocks of water and firewood are updated.

In order to quantify food stability, measures of production stability, market stability and political stability are first calculated. This involves calculating the coefficient of variation (CV) for a number of indicators. Production stability is evaluated based on the CV of monthly crop production. Market stability considers variation in annual grain price. Political stability is the average CV of the proportion of households with i) access to inputs and ii) access to payment for work schemes. Lower CV values suggest greater stability of output (and vice versa). A simple fuzzy inference system is then employed to give a value of food stability between 0 and 100, with 0 being the lowest and 100 the highest. The overall food security status of households is then determined using a further fuzzy inference system. This time taking into account food availability, access, utilization and stability, each household returns a food security value between 0 and 100, with 0 being lowest and 100 highest.

3.1.9 Adjust household type

At the end of the agricultural season, a household may adjust its 'type' to suit the prevailing livelihood strategy. This is based upon the proportion of time that was spent by the household upon farming, agricultural labour and non-agricultural activities over the past year. In order to create fixed thresholds with which to categorise households, a classification and regression tree (CART) was developed. Results from the initial cluster analysis performed by Dobbie *et al*. (under review) were used to construct the classification tree (Fig. 4). Simple 'IF ELSE' rules were then developed to determine the type of a household at the end of each simulated agricultural season.

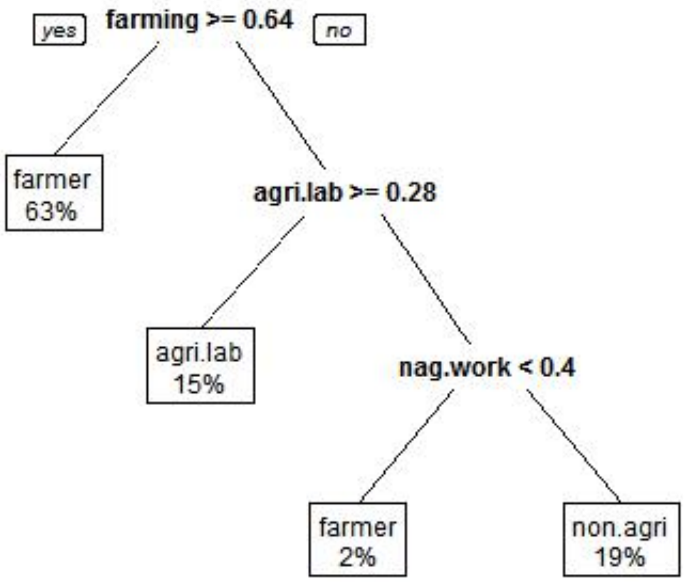


Figure 4. Classification and regression tree (CART) to distinguish between farmers, agricultural labourers and non-agricultural workers based upon the proportion of time spent of different livelihood activities.

Over time, the dynamic nature of livelihood strategies causes households to follow one of four trajectories: i) hanging in ii) stepping up iii) stepping out or iv) falling down (Dorward et al. 2009; Falconnier et al. 2015). In this case, households maintaining the same household type as before are considered to be 'hanging in'. Households who continue with the same household type, but have a greater yield and or income compared to previous years are considered to be stepping up. Those households who move to a type of higher yields and / or income are classified as 'stepping out' and households following a trajectory of declining yields and income are regarded to be 'falling down' (Dorward et al. 2009; Falconnier et al. 2015). Under this framework, previous results described by Dobbie *et al*. (under review) imply that agricultural labourers may step out to become either farmers or non-agricultural labourers. Farmers on the other hand may step out to become non-agricultural workers or fall down to become agricultural labourers, whilst non-agricultural workers may only fall down to become either farmers or agricultural labourers (Fig. 3).

3.2 Initialisation

This section outlines the model initialisation process. All initialisation data are read from text files at the beginning of each simulation.

3.2.1 Initialisation of Households and Individuals

To represent a hypothetical village within Southern Malawi, data corresponding to 116 unique households is drawn from a sample of the IHS3 dataset (n=2492). The same sample set was used to construct the initial household typology (Dobbie *et al.*, in review). For each household a number of attributes are drawn from the survey data. These include: household size, household type (farmer, agricultural labourer or non-agricultural worker) financial capital and livestock. Attributes of individuals corresponding to the selected households are also initialized using survey data. Gender, age, education level, household status and health of individuals are drawn from the IHS3 dataset. A total of 546 individuals are initialised. A summary of attribute values at initialisation can be found in Table 2.

Table 2. Summary of attribute variables at initialisation for households, individuals and agricultural land.

Attribute	Full Sample		Farmers		Agricultural Labourers		Non-agricultural workers	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Households								
n	116		73		15		28	
Household size	4.7	2.2	4.7	2.3	5.1	2.1	4.4	2.0
Financial capital (USD)	10.7	37.9	13.6	40.7	8.0	38.0	4.4	29.6
No. of cattle	0.1	0.3	0.1	0.5	0	0	0	0
No. of poultry	2.4	4.9	2.1	4.1	1.4	2.5	3.8	7.1
Individuals								
n	546		346		76		124	
Age	21.7	19.8	22.1	20.2	22.6	19.9	20.3	18.5
Education level	0.48	0.60	0.45	0.63	0.45	0.50	0.49	0.58
Agricultural land								
n	98		62		10		26	
No. of farm plots owned	1.9	1.1	2	1.1	1.5	0.8	1.8	1.1
No. of dimba plots owned	0.1	0.3	0.1	0.4	0	0	0	0.2
Total area of land owned (ha)	0.54	0.45	0.57	0.47	0.32	0.29	0.57	0.44

3.2.2 Initialisation of the environment

Attributes of farm plots and dimba patches corresponding to each of the households are also taken from the sampled IHS3 dataset. These include patch area in addition to past allocations of crop types and applications of inputs in the form of pesticides and inorganic fertiliser. The IHS3 does not contain village level data on the area of cropland, water and forest. Instead analysis of land cover data from Masdap (www.masdap.mw/) and GlobCover 9 (http://due.esrin.esa.int/page_globcover.php) enabled the area of cropland, water and forest to be approximated for 7121 rural villages within Southern Malawi. The average proportions of different land types present within each village were then calculated. Typically village land cover comprised of 31.6 % cropland, 67.8 % forest and 0.7 % water. This was used to generate values for areas of forest and water, based upon the total amount of farmland owned by the sampled households (n=166).

3.3 Input data

3.3.1 Climate data

Climate variability is represented by annual rainfall. At the beginning of each model year, a value is drawn from a list of rainfall data. This list was generated using MarkSim, a third-order Markov rainfall generator that can be employed as a Global Climate Model (GCM) downscaler (Jones & Thornton 2013). Daily rainfall projections for Malawi were generated from 2010 to 2050. This was based upon the average output of 17 GCM's using the RCP2.6 scenario, as defined by the IPCC (van Vuuren et al. 2011). Daily values were then aggregated to give an estimate of annual rainfall (See Fig. 5).

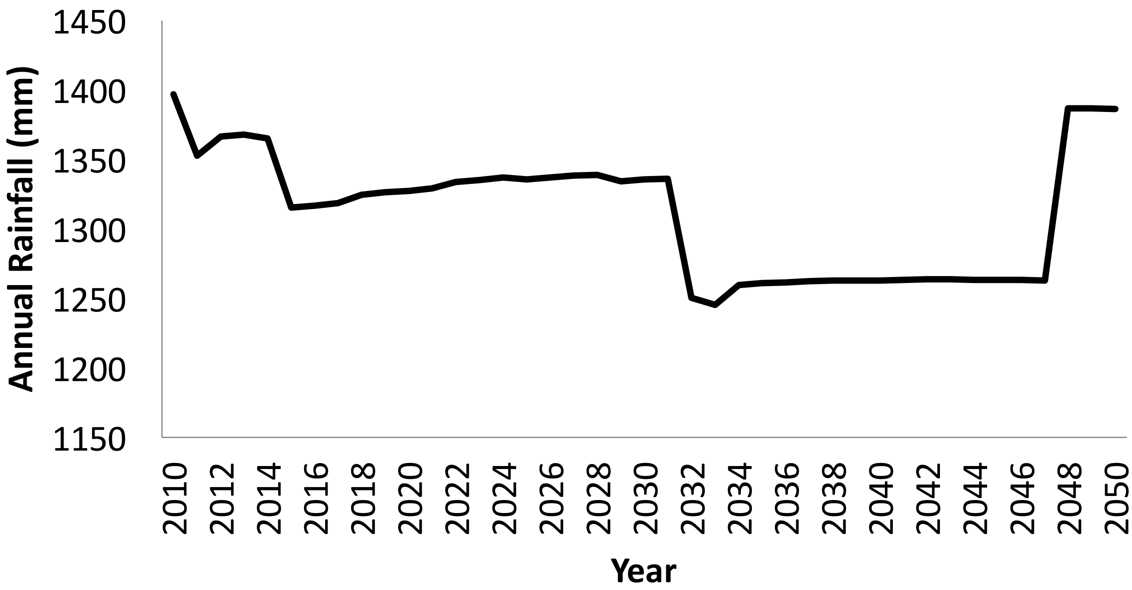


Figure 5. Annual rainfall projections for Malawi generated using MarkSim (Jones & Thornton 2013).

3.3.2 Population growth

Village-level population growth was approximated using rural population projections from the 2014 revision of world urbanisation prospects (UN 2015). As projections consider the number of individuals only, the growth in household numbers at the village level had to be estimated. This was achieved using the simple equation:

$$hh = rpop * prop / hhsize \qquad (2)$$

where *hh* is the number of households, *rpop* are the rural population projections (UN 2015), *prop* is the proportion of rural individuals living in Southern Malawi and *hh-size* is the average size of households (based on census data for 1987, 1988 and 2008) (See Fig. 6). In order to simulate population growth, at the end of each model year, the number of new households to be created is read from a list. Households and individuals are created and initialized accordingly, drawing upon data from IHS3. In order to allocate patches, each new household asks a member of its social network to spare their smallest patch of fallow land. Patches may also be split. This reflects the matrilineal nature of customary land tenure in Malawi (Takane 2008). It should be noted however, that for this model version, household demographics have been simplified considerably. Neither households nor individuals age over time. Instead, new households are simply added at the end of each agricultural season and existing households continue with the same attributes as before.

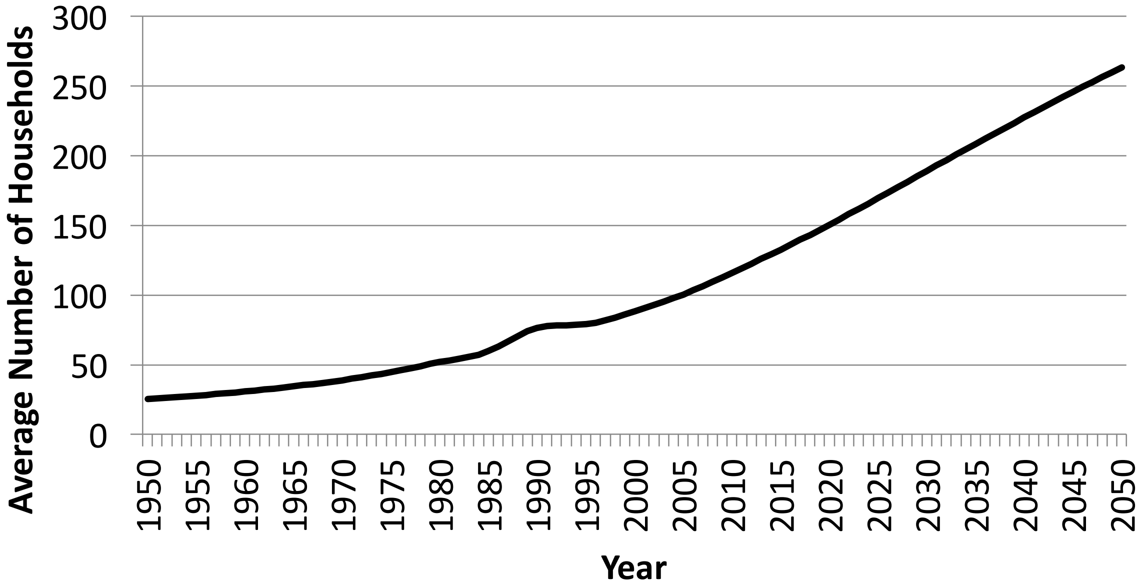


Figure 6. Population projections for rural Southern Malawi based upon UN (2015). Average numbers of households per village are given.

3.3.3 Markets

The local market prices for 11 food categories are provided as inputs to the agent-based model at initialization. The model stores the annual market price of these commodities starting at 2010 for the following 40 years. The market value of crops and livestock products such as milk, eggs and meat play an important role within the model. Changes over time are simulated using two well established global models: AGLINK-COSIMO (OECD & FAO 2015) and GCAM4.0 (Kyle et al. 2011; Capellán-pérez et al. 2014). AGLINK-COSIMO is a recursive-dynamic, partial equilibrium model used to simulate developments of annual market balances and prices for the main agricultural commodities produced, consumed and traded worldwide. GCAM is a dynamic recursive economic partial-equilibrium model driven by assumptions about population size and labour productivity that determine potential gross domestic product in market exchange rates in 14 geopolitical regions. It combines representations of the global economy, energy systems, agriculture and land use, with a representation of terrestrial and ocean carbon cycles and a suite of coupled gas-cycle, climate, and ice-melt models.

The first 4 years (2010 to 2014) are based upon empirical data. The value is expressed in USD/kg, using reference values from either IHS3 (NSO, 2012), or the World Food Programme database of market prices (http://foodprices.vam.wfp.org/Default.aspx), according to data availability. For the following years we apply to the baseline value of 2014, the percentage price change provided by the models described above. This is an important assumption that allows us to override the local inflation and currency exchange rate. From 2015 to 2025, we applied the annual percentage price change provided by the AGLINK-COSIMO model. As the model does not simulate national prices for Malawi, average values associated with three neighbouring countries: Tanzania, Zambia and Mozambique, are taken. From 2025 on, trends were applied from the simulated global prices of GCAM4.0 assuming the representative concentration pathway (RCP) 2.6 as the climate change scenario (van Vuuren et al. 2011) and the absence of carbon taxation on CO_2 from land-use changes. As this model produces simulated prices at 5 year intervals, we split the aggregate 5 year changes uniformly to generate annual price changes.

4. References

Agrawal, A. et al., 2013. Interactions between organizations and networks in common-pool resource governance. *Environmental Science and Policy*, 25(August 2015), pp.138–146.

Bosma, R. et al., 2012. A generic methodology for developing fuzzy decision models. *Expert Systems with Applications*, 39(1), pp.1200–1210.

Capellán-pérez, I. et al., 2014. New climate scenario framework implementation in the GCAM integrated assessment model. , (July), pp.1–48.

Chambers, R. & Conway, G., 1991. Sustainable rural livelihoods: practical concepts for the 21st century. *IDS Discussion Paper*, 296, p.29.

Dobbie, S., Dyke, J.G. & Schreckenberg, K., *Typology Creation and Livelihoods Analysis to Support Food Security Policy in Rural Southern Malawi*,

Dorward, A. et al., 2009. Hanging in, stepping up and stepping out: livelihood aspirations and strategies of the poor. *Development in Practice*, 19(2), pp.240–247.

Falconnier, G.N. et al., 2015. Understanding farm trajectories and development pathways: Two decades of change in southern Mali. *Agricultural Systems*, 139, pp.210–222.

GoM, 2009. *The Malawi Growth and Development Strategy Annual Review 2009, an assessment of the annual achievements for the 2008/09 government financial year*, Lilongwe, Malawi.

Jones, P.G. & Thornton, P.K., 2013. Generating downscaled weather data from a suite of climate models for agricultural modelling applications. *Agricultural Systems*, 114, pp.1–5.

Kranton, R.E., 1996. Reciprocal exchange: A self-sustaining system. *The American Economic Review*, 86(4), pp.830–851.

Kyle, P. et al., 2011. GCAM 3.0 Agriculture and Land Use: Data Sources and Methods.

Machálek, T. et al., 2013. Fuzzy Methods in Land Use Modeling for Archaeology. *Proc. of 31st International Conference on Mathematical Methods in Economics 2013, Jihlava, part II*, pp.552–557.

NSO, 2012. *Integrated Household Survey 2010/11 (IHS3): NSO*, Zomba, Malawi.

OECD & FAO, 2015. *Aglink-Cosimo Model Documentation: A partial equilibrium model of world agricultural markets.*, Available at: http://www.agri-outlook.org/database/.

Scoones, I., 1998. Sustainable Rural Livelihoods a Framework for Analysis. *IDS Working Paper*, 72, pp.1–22.

Smith, L.C. & Subandoro, A., 2007. *Measuring Food Security Using Household Expenditure Surveys*, Washington, D.C.

Takane, T., 2008. Customary Land Tenure, Inheritance Rules, and Smallholder Farmers in Malawi* . *Journal of Southern African Studies*, 34(November), pp.269–291.

UN, 2015. *World Urbanisation Prospects*, New York. Available at: http://esa.un.org/unpd/wup/.

van Vuuren, D.P. et al., 2011. The representative concentration pathways: An overview. *Climatic Change*, 109(1), pp.5–31.

Watts, D.J. & Strogatz, S.H., 1998. Collective dynamics of “small-world” networks. *Nature*, 393(6684),

pp.440–2.
Wilensky, U., 1990. *Netlogo*, Evanston, IL. Available at: http://ccl.northwestern.edu/netlogo/.
Zadeh, 1965. Fuzzy Sets. *Information and Control*, 8, pp.338–353.
Zadeh, L., 1996. Fuzzy logic equals Computing with words. *Ieee Transactions on Fuzzy Systems*, 4(2), pp.103–111.